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Understanding the Microphysical Properties of Developing Cloud Clusters During TCS-08

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LONG-TERM GOALS

To improve understanding of tropical cyclone genesis is through a research program that focuses on identifying the environmental and microphysical differences between developing and non-developing cloud clusters in the western North Pacific.

OBJECTIVES

The objective is to identify the environmental and microphysical differences between developing and non-developing cloud clusters in the western North Pacific. Specific investigations include:

1. detailed investigation of genesis using observations gathered during the TCS-08 field campaign.
2. detailed investigation of genesis using remote-sensed observations from platforms that are maintained on a more permanent basis including satellite-based infrared, visible, and microwave imagers and long-range lightning detectors.
3. utilizing model-based microphysical sensitivity studies to better understand the observed cloud microphysical differences between developing and non-developing cloud clusters.
4. generalized study that aims to build an ability to detect and classify developing and non-developing cloud clusters using remote-sensing platforms alone.

Through diagnostic analysis of the detailed field observations combined with remotely-sensed platforms and model sensitivity studies, insights will be gained that will contribute to improvement of the forecasts associated with tropical cyclone genesis, particularly in the western North Pacific Basin.

APPROACH

Our overarching hypothesis is that there are significant microphysical differences between developing and non-developing cloud clusters. If these differences can be identified with high-fidelity field observations then we can take two major steps to improve understanding of tropical cyclogenesis. First, we can investigate methods to identify the differences in developing and non-developing cloud

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clusters ahead of time. Second, because we can measure the mesoscale environment that the cloud cluster developed in, we can better understand the mesoscale environmental conditions required to form a developing cloud cluster, and we can investigate whether the vortex-stretching and concentration necessary for cyclogenesis occurs within mesoscale (100km – 300 km) stratiform updrafts, or whether it is first achieved on the smaller scale of convective scale (~10 km) updrafts that interact and contribute individually to the mesoscale vorticity concentration. The aircraft- and satellite-based observations that were gathered during the TCS 2008 field campaign (TCS-08: http://met.nps.edu/~tparc/TCS-08.html) will be analyzed for insights into relationships between near-cluster environment and convective activity within the cluster, and also for relationships between convective activity and overall intensification into a tropical cyclone. Finally, a high-resolution, full-physics mesoscale model will be used to investigate the microphysical differences between developing and non-developing cloud clusters.

WORK COMPLETED

A lightning study using the Long-range lightning detection network (LLDN) looking at differentiation between developing and non-developing cloud clusters for the eastern North Pacific 2006 season has been published (Leary and Ritchie 2009). This work has being extended using the new Vaisala GLD360 lightning dataset to include more years to improve the statistical characterization of the cluster groups and more basins, in particular the western North Pacific. The work is currently being written up for publication (Mazzarella and Ritchie 2012).

An observational study of remotely-sensed microphysical characteristics of developing and non-developing cloud clusters is ongoing. The eastern North Pacific basin is the current focus for this work so that a comparison with the above-mentioned lightning studies can be accomplished. A database of MODIS measurements from the AQUA and TERRA satellites has been compiled and comparisons with a database of developing and non-developing North Pacific cloud clusters has been completed and is being submitted for publication in the *IEEE Transactions in Geosciences and Remote Sensing*.

A methodology to automate the cloud cluster tracking is being developed for the entire Pacific basin. While the immediate application is to automate the lightning flash rate counts, the automated tracking will also support the broader remotely-sensed microphysical efforts. Images are stitched together from various geostationary satellites to form a contiguous scene of the Pacific. The deviation angle variance (DAV) technique described in a companion report is used to automatically track cloud clusters.

Sensitivity experiments with the WRF-ARW model have been run at high-resolution on some western North Pacific TC cases. In these simulations, the microphysical properties of the cloud-resolving models are varied in order to assess the impact on the formation and evolution of the tropical cyclones. Various runs have been run to test the following aspects of the model setup:

a) Boundary condition sensitivity: 3 model runs carried out on different outer domain specifics including position, extent and resolution. An optimal arrangement was found which balanced the sensitivity to boundary forcing (FNL analysis), the predicted storm track and the computational cost. A 27km outer domain was selected with nests at 9km, 3km and 1km (used only for certain studies).

b) Implementation of FDDA spectral and analysis nudging on the parent domain: Tests were carried out using the parent (27km) domain to investigate the value of using various FDDA nudging options on the simulation. Spectral nudging has proved to be useful for use in other applications such as

climate downscaling simulations using regional models. The main purpose of the nudging is to preserve the large-scale characteristics of the forcing data within the interior of the domain. The value of this technique for high-resolution modeling of a case study tropical storm has not been extensively reviewed and hence some parametric investigation was necessary.

The goal of the spectral nudging in this case was to preserve the large scale environmental forcing in the proximity of the storm (by nudging the outer domain) but to allow the model to spin-up and balance its own meso- and micro-scale dynamics. Sensitivity tests were carried to using a range of nudging parameters, which included: Nudging strength (quantified by the relaxation time), vertical profile of the nudging and combinations of variables subjected to nudging (mass, momentum and energy). The sensitivity testing amounted to ten simulations on the parent domain. It was found that on a single domain, spectral nudging (even with relatively small magnitudes) provided a significant advantage in closely reproducing the storm track. Without nudging, the model was unable to spin up a storm in the correct region. The storm track was very insensitive to the nudging parameters however once the inner domains were included, the influence of the nudging on the storm track was significantly reduced since the inner domains were not nudged.

c) Sensitivity to microphysical processes: A model comparison of the microphysical processes involved in the genesis and subsequent intensification of Typhoon Sinlaku was carried out using six of the microphysics schemes available in WRF. Five of the six have been completed (using a 3 nest configuration) and the sixth is currently in progress. The two inner nests were configured to track the vortex following an initial 48hrs where the nests were static, which roughly corresponded to the pre-genesis phase of the storm. The schemes used in the comparison covered a range of increasing complexity and included: WRF Single Moment 3-class, WRF Single Moment 5-class, (Lin et al. 1983), WRF Double Moment 6-class (Thompson et al., 2004), and (provisionally) the NSSL 2-Moment 6-class (with prescribed CCN).

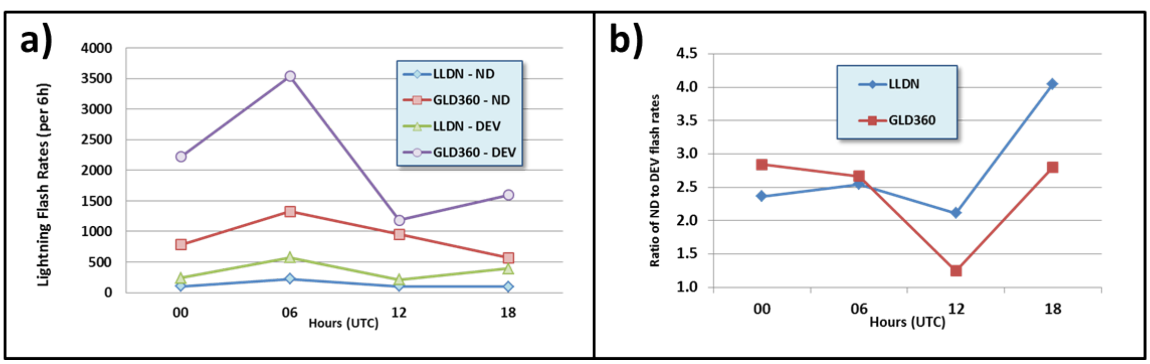

Figure 1: Average flash rates for 6-h periods for the 2010 season showing a comparison between the LLDN and GLD360 datasets: a) average flash rates for each 6-h period for non-developers and developers; and b) the ratio of non-developers to developers for each 6-h period.

RESULTS

a) Lightning studies

Results comparing Vaisala's Long-Range Lightning Detection Network (LLDN) (Demetriades and Holle, 2005), and the new GLD360 dataset from Vaisala, have re-confirmed the results of Leary and Ritchie (2009) that there are differences in the lightning flash rates associated with developing cloud clusters compared with non-developing cloud. The GLD360 tends to detect many more lightning flash rates than the LLDN (Figure 1) because of the increased efficiency of the network with distance from the coast. The increase is a ratio of about 6:1. However, a comparison of the 2010 season indicates that while the GLD360 detects many more lightning flashes, the overall ratio of non-developing to developing flashes remains about the same: 2.7:1 for the LLDN compared with 2.4:1 for the GLD360. Thus, we are encouraged, that the overall results of the Leary and Ritchie (2009) study are robust, and that with the increased efficiency of the GLD360 dataset, lightning flash rates can be investigated as a discriminator for genesis for cloud systems that are located well away from the coast.

Another interesting feature is shown in Figure 1. A certain amount of the nighttime maximum in flash rates in the LLDN was attributed to the increased detection efficiency at night. However, the GLD 360 also exhibits a higher flash rate at night that can be attributed to the nocturnal diurnal maximum for oceanic convection.

b) Remotely-sensed satellite data

In addition to the lightning data, geostationary infrared brightness temperatures and MODIS data have been used to analyze differences in cloud microphysical structure in developing and non-developing cloud clusters. The working hypothesis is that developing cloud clusters demonstrate elevated lightning flash rates compared to the non-developing cloud clusters and thus appear to have differing levels of convection. Therefore, they should have marked differences in the cloud microphysical characteristics at the cloud top. Consistent with this, results that tracked tropical cloud clusters in the eastern North Pacific during the 2010 hurricane season that formed in similar synoptic conditions over similar sea surface temperatures suggest there are important microphysical differences in the cloud properties above 150 hPa (Fig. 2).

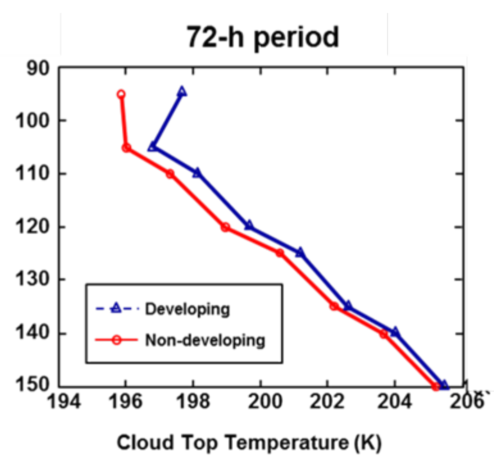

Figure 2: The mean cloud-top temperature plotted against cloud-top pressure for a 72-h period for developing (blue) and non-developing (red) cloud clusters.

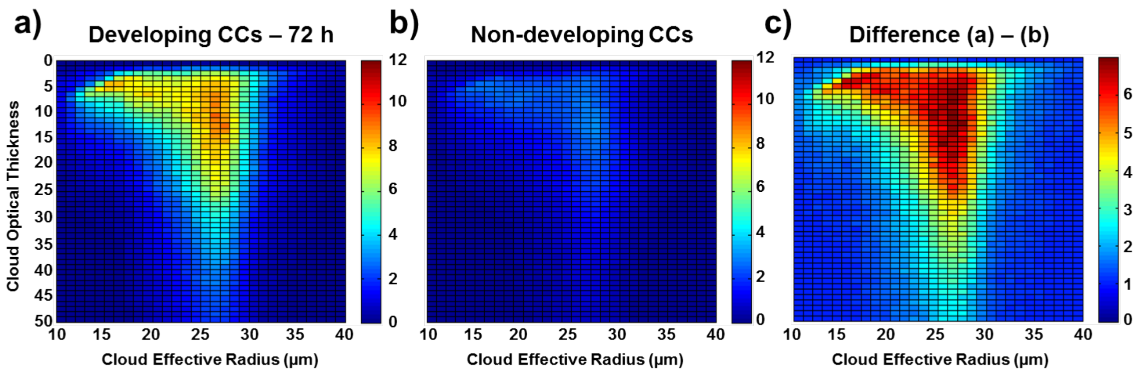

Figure 3: Cloud effective radius versus cloud optical thickness normalized frequency plots for a 72-h period for: a) developing cloud clusters; b) non-developing cloud clusters; and c) the difference between the two.

There are significant differences in the frequencies of cloud optical thickness versus cloud effective radius in these two groups of clusters (Fig. 3), and the same can be said for cloud-top pressure and cloud effective radius. There are more occurrences of colder cloud-top temperatures, thicker clouds, and higher amounts of larger cloud particles (Fig. 4). Furthermore, there is a difference in the time evolution of the cloud properties between developing and non-developing cloud clusters. It appears that the convective activity in non-developing clouds clusters, while weaker, is very consistent for each 24-h period. In contrast, developing cloud clusters tend to be more convectively active leading up to the 24-h period prior to TD designation and then there is a lull in activity just prior to development into a TD when convective activity re-initiates (\Barnard and Ritchie 2012)). The exact processes that are occurring during this lull are unclear from these data. However the profile of mean cloud-top temperature versus cloud- top pressure suggests that significant upper-level warming is occurring within the cloud cluster, perhaps associated with the development of a nascent warm core similar to that reported in McBride (1981) from aircraft data in the western North Pacific.

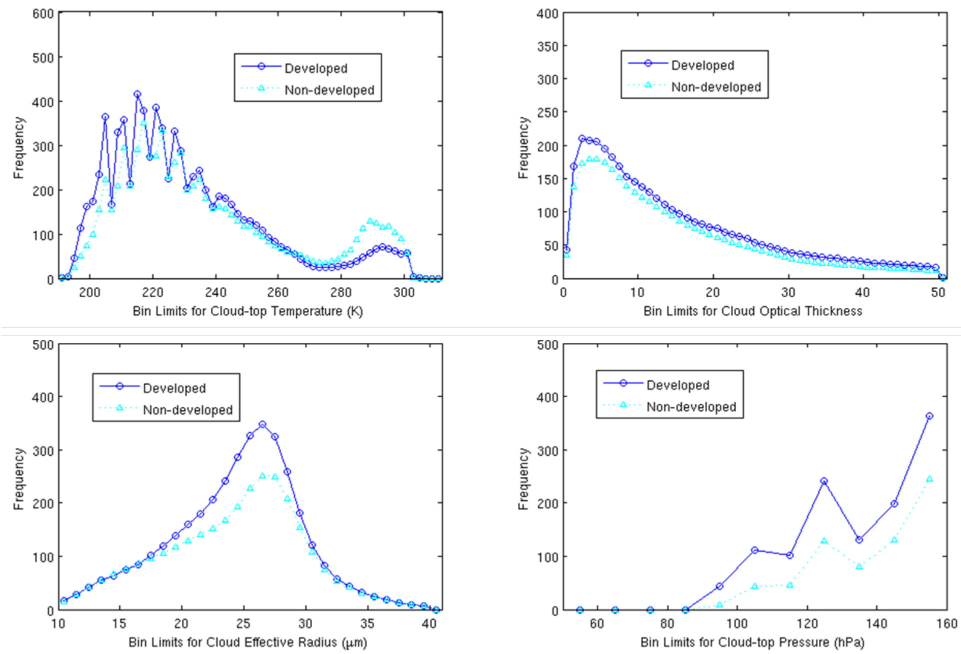

Figure 4: Comparison between developing (dark blue) and non-developing (cyan) cloud clusters over the entire 72-h period of comparison for each cloud property: a) cloud-top temperature; b) cloud optical thickness; c) cloud effective radius; and d) cloud-top pressure.

c) High resolution model sensitivity simulations

High-resolution (1.67-km) microphysics sensitivity simulations of Typhoon Mawar (2005) from the western North Pacific have been analyzed in order to diagnose the different microphysics processes responsible for the differences observed in section *b)*. Depending on the microphysics package used, considerable differences in the outcomes of the typhoon are simulated (shown in previous report). Initial calculations of some basic cloud properties from infrared imagery courtesy of NRL--Monterey for Typhoon Mawar indicate that many of the microphysical schemes may be over-active in terms of the amount of, and intensity of deep convection (shown in previous report).

More recently we have been simulating the very early stages of Typhoon Sinlaku (2008). This has the advantage that Sinlaku developed during the TCS-08 field campaign and was probably the most intensively observed system during that campaign. Advantages of these observations are that we can properly document the actual structure of Sinlaku at key times during its development (e.g., Fig. 5) and compare the simulated structure to better understand whether the model is appropriately simulating both the cloud structure and the dynamic/thermodynamic structure of the evolving storm.

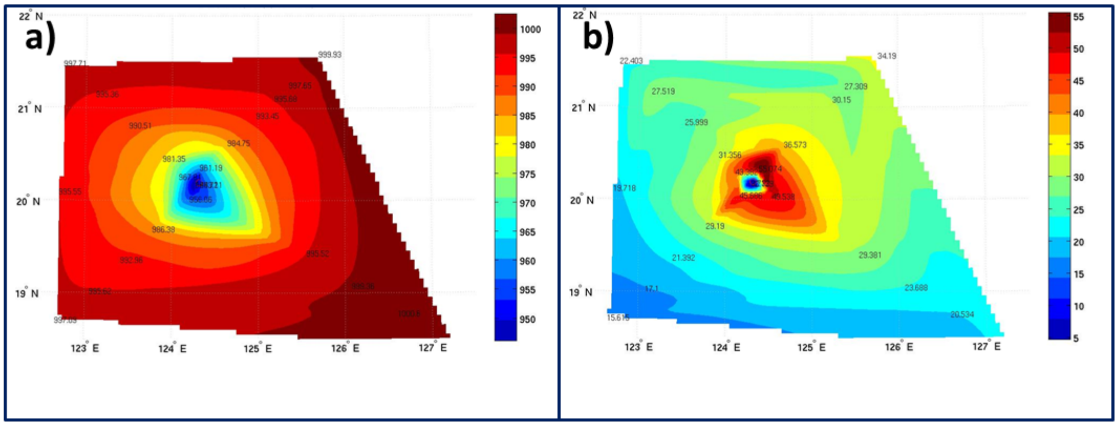

Figure 5. Analysis of the field observations in TY Sinlaku (2008) on the 9th of September: a) sea-level pressure (minimum 950 hPa); and b) tangential winds at 1,500 m. Note the slight wavenumber 1 asymmetry in the center due to a slight mismatch of the actual Sinlaku circulation center during the analysis.

Fig 6. shows the maximum surface winds for five microphysics sensitivity tests. The JTWC best track data for Typhoon Sinlaku are shown in black for comparison. The WRFSM-3 scheme (a simple cold cloud scheme) does not adequately simulate any of the features of the developing storm, significantly under predicts convective cloud, and fails to produce a coherent vortex. The Thompson scheme is the most intense and therefore is the closest to the best track in terms of peak intensity. The other schemes perform in a very similar. A common shortfall across all simulations was the failure to rapidly intensify during day 3 (hours 48-72). All except the WRFSM-3 intensified during day 4 however at a reduced rate. This aspect is under continuing investigation.

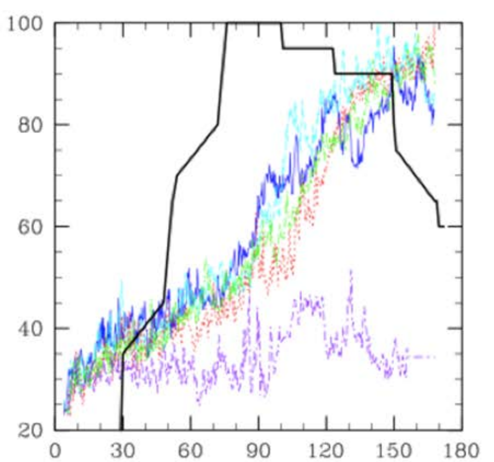

Figure 6. Maximum wind for several realizations of TY Sinlaku (2008) using different microphysics schemes. The JTWC best track intensity is plotted in black for comparison.

Figure 7 shows a snapshot of the outgoing long wave radiation (OLR) for each of the simulations. The OLR can be interpreted as a simple proxy for quantifying deep convection and highlights the location of the coldest cloud tops. The Thompson scheme shows a more extensive coverage of cold cloud tops than the other schemes and inner core structure of the storm appears more realistic. Notably, the eye-wall radius for the Thompson scheme is at approximately 15 km compared to, for example, the Lin scheme which creates an eye-wall at a rather unrealistic radius greater than 60 km. The WRFSM-3 scheme does not simulate extensive deep convection.

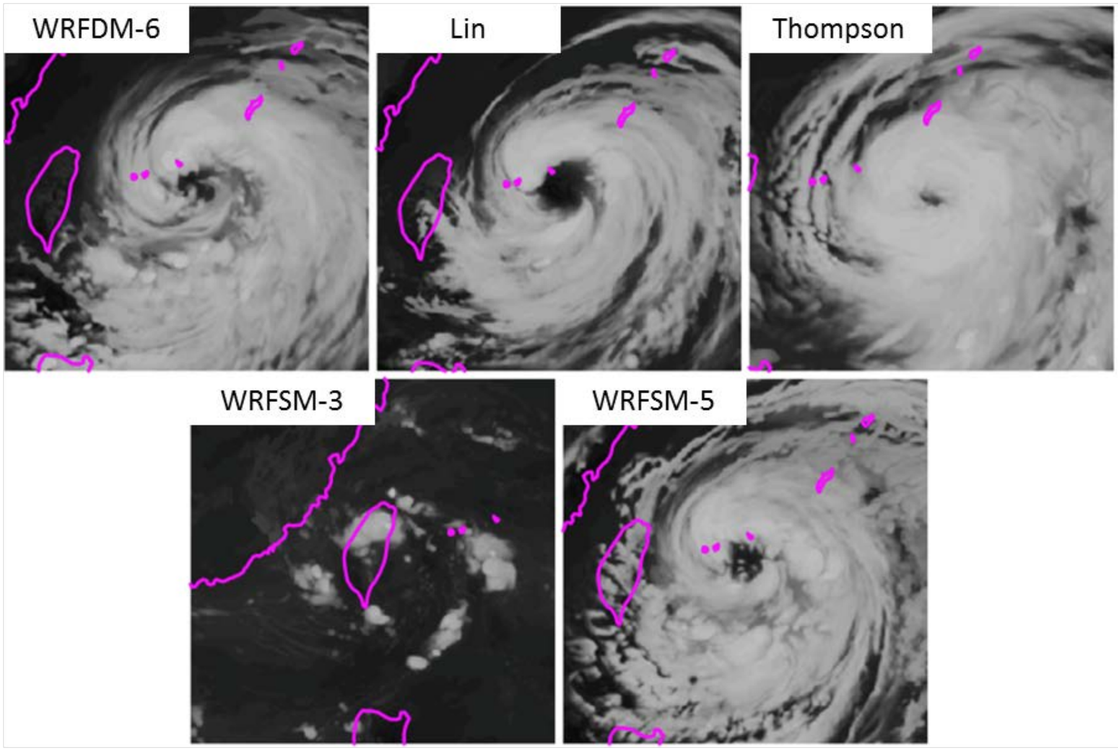

Figure 7: Outgoing Long-Wave Radiation at 150-h of simulation after the simulated Sinlaku has developed a stable eye.

IMPACT/APPLICATIONS

An observational study of North Pacific tropical cloud clusters is being conducted. The microphysical properties of the cloud clusters (as observed from remotely-based instruments as well as special field-program platforms) are studied to see if there are clear differences in the convective structure of cloud clusters that develop compared with those that don't. The documentation of high-resolution structural responses in the cloud clusters during tropical cyclogenesis will allow us to gain more insight into the physical processes that lead to genesis. The greatest value-added asset would be the development of a technique that will help to accurately predict genesis of tropical cyclones using remotely-sensed data that differentiate these key physical processes. There is already potential for this technique shown with the use of the GLD360 data.

RELATED PROJECTS

None.

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